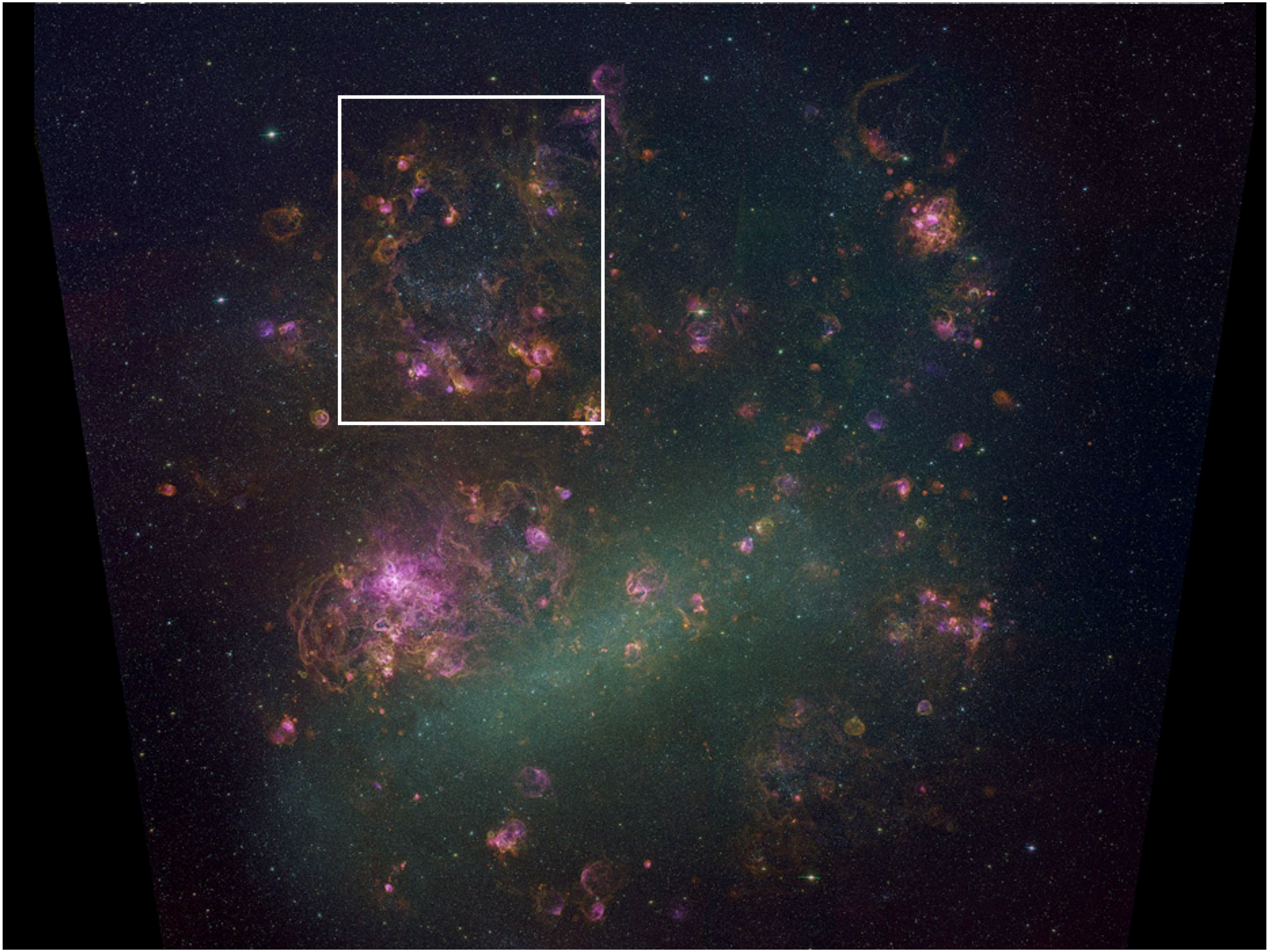
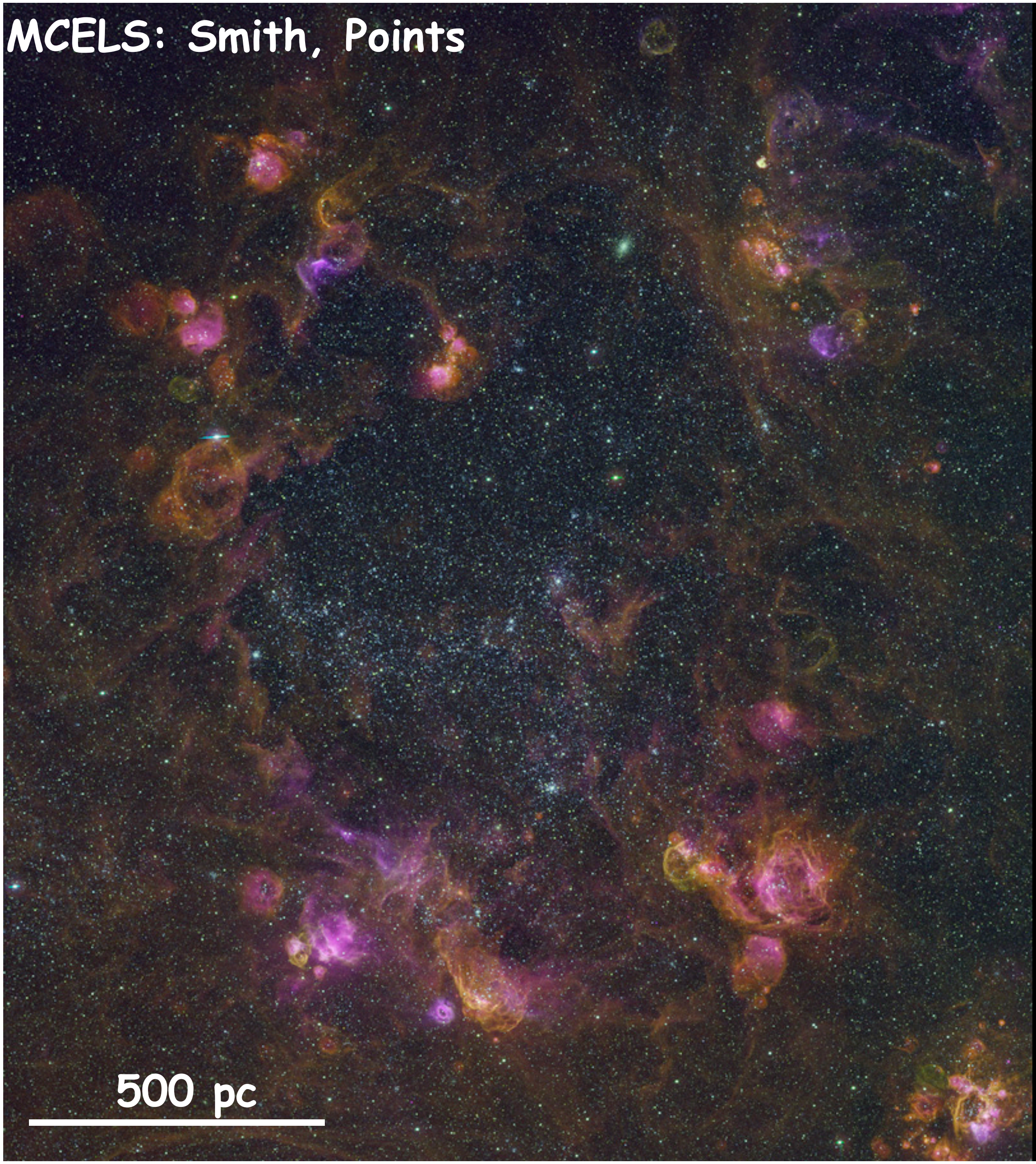




Supergiant shells
~ 1000 pc
~ 10^7 yr
(multi generations)

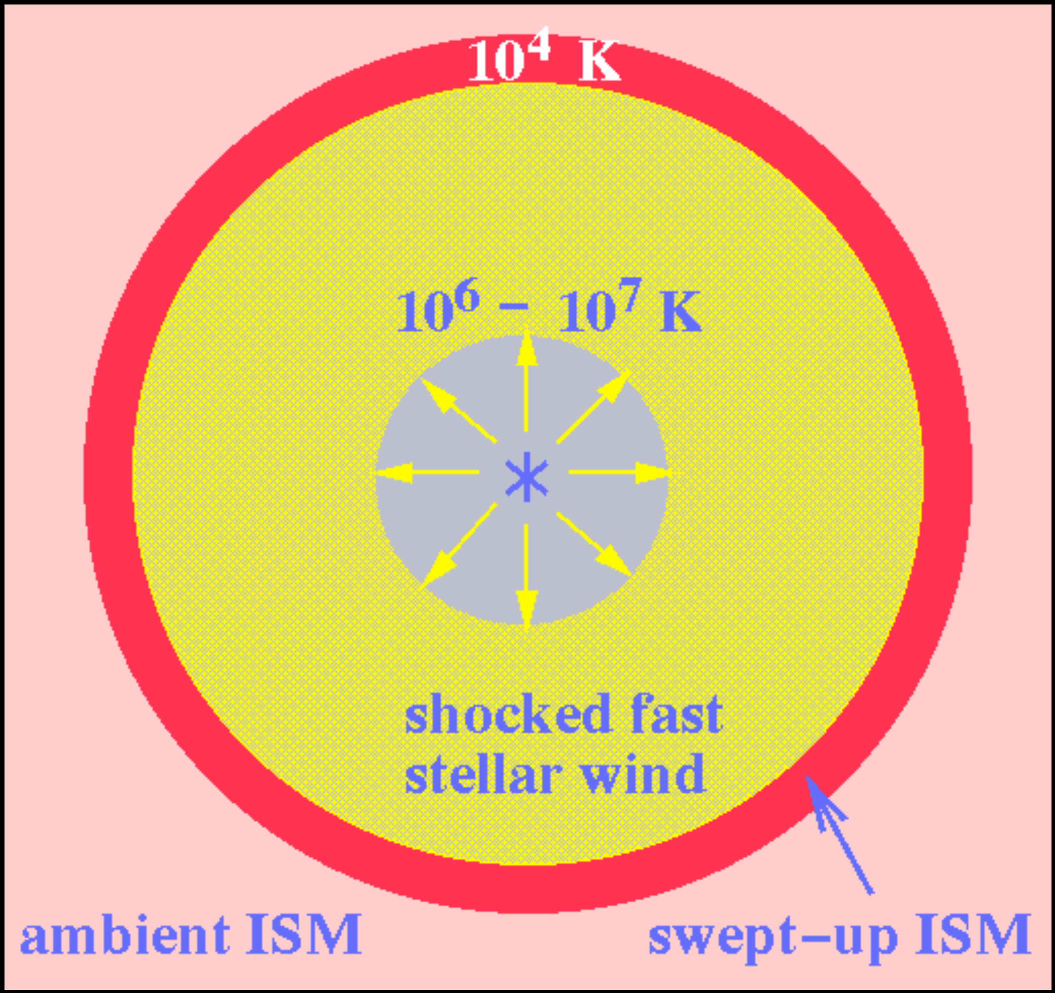
Superbubbles
~ 100 pc
~ 10^6 yr
(OB associations)

Bubbles, SNRs
~ 10 - 50 pc
~ 10^3 - 10^5 yr
(single star)

R - Hα
G - [S II]
B - [O III]

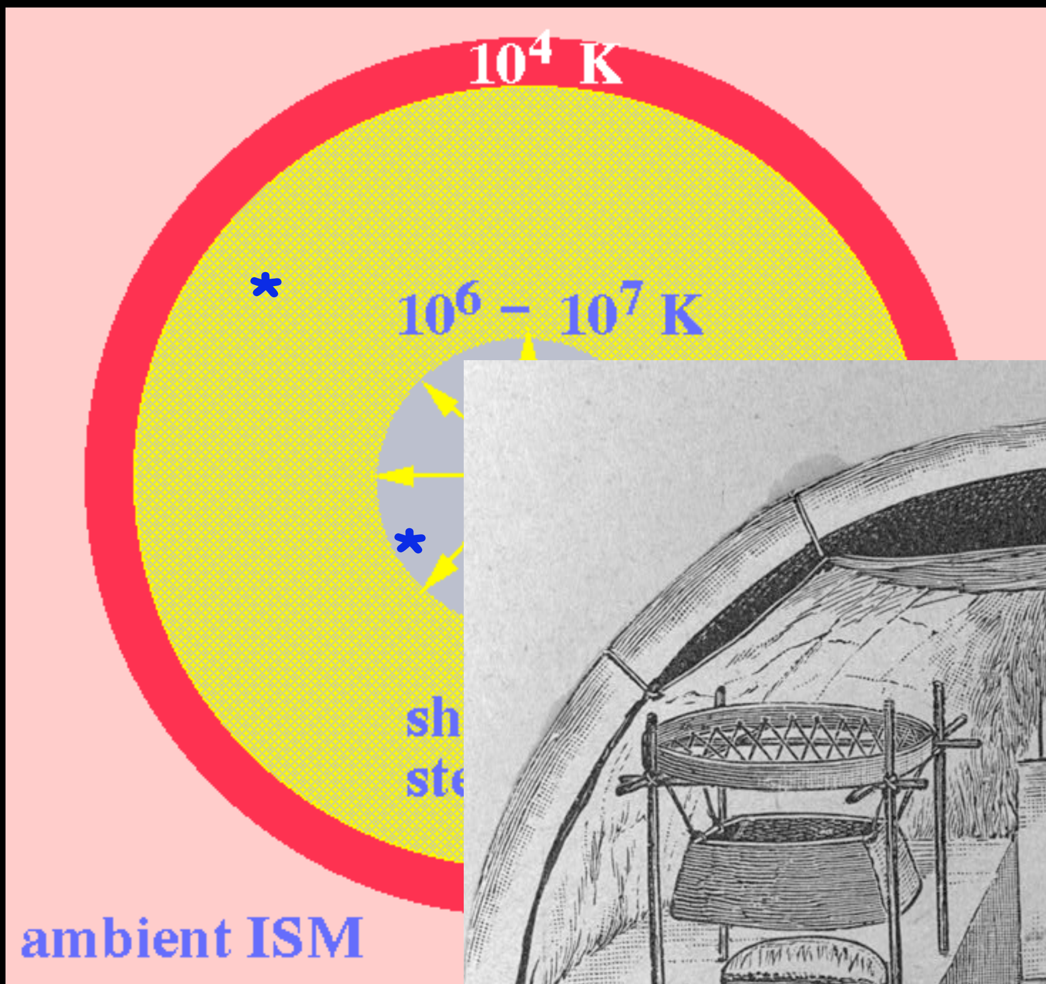
Interstellar Bubble Model

Weaver et al. 1977



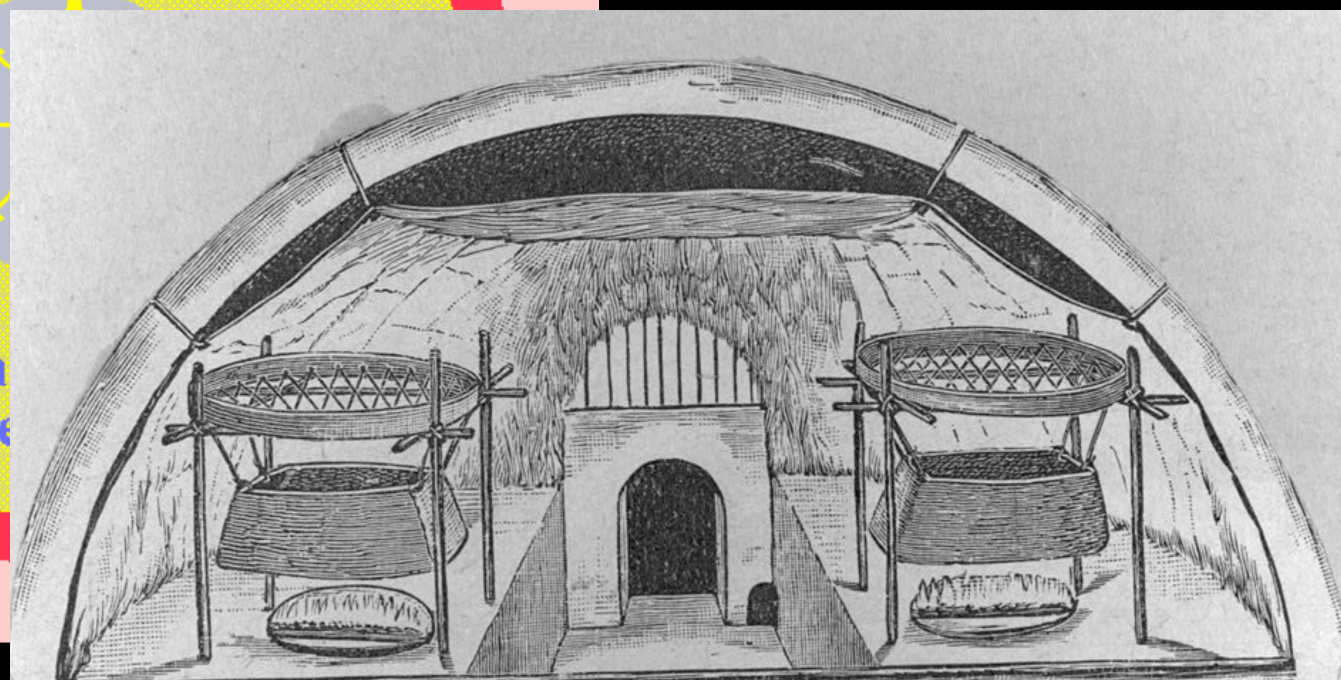
Interstellar Bubble Model

Weaver et al. 1977

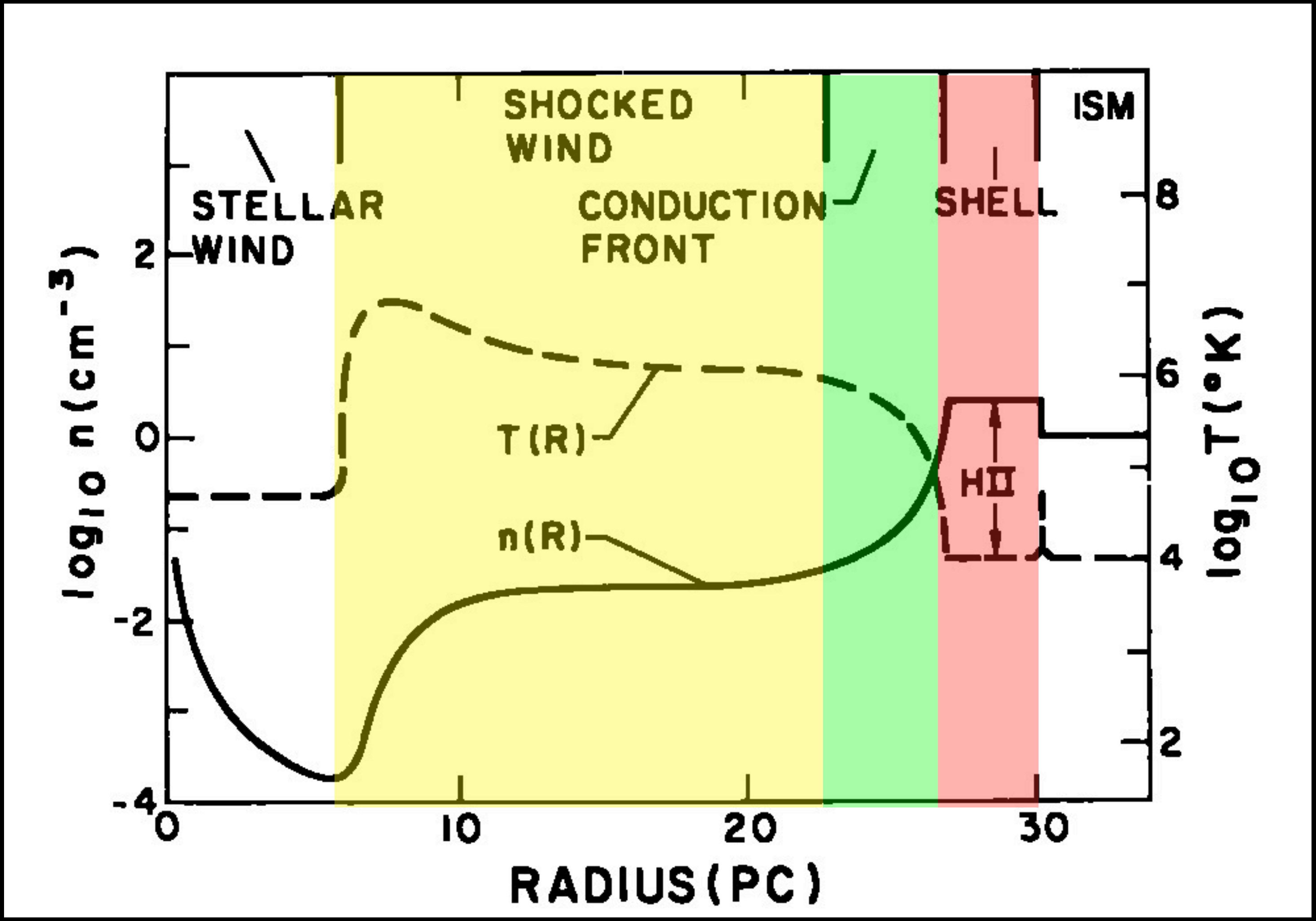


Igloo:

A Better Model Of Superbubble



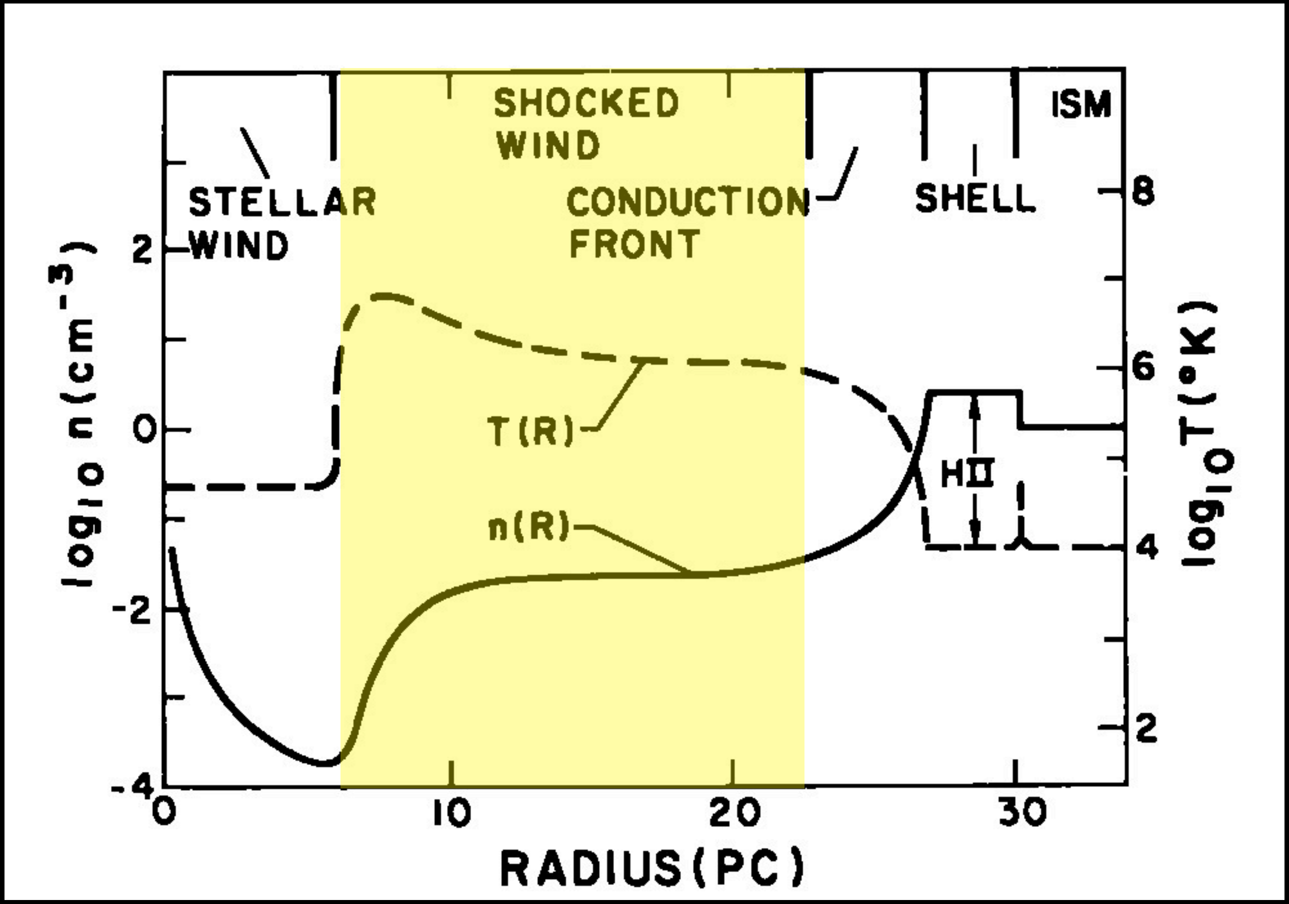
Schematic Bubble Structure



Weaver et al. 1977

I. Hot Bubble Interior

X-ray emission from bubble interior



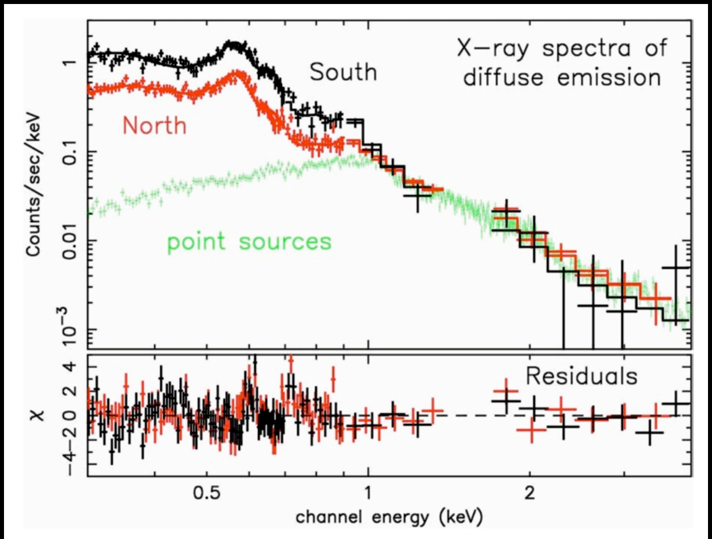
Hot Gas in the Orion Nebula

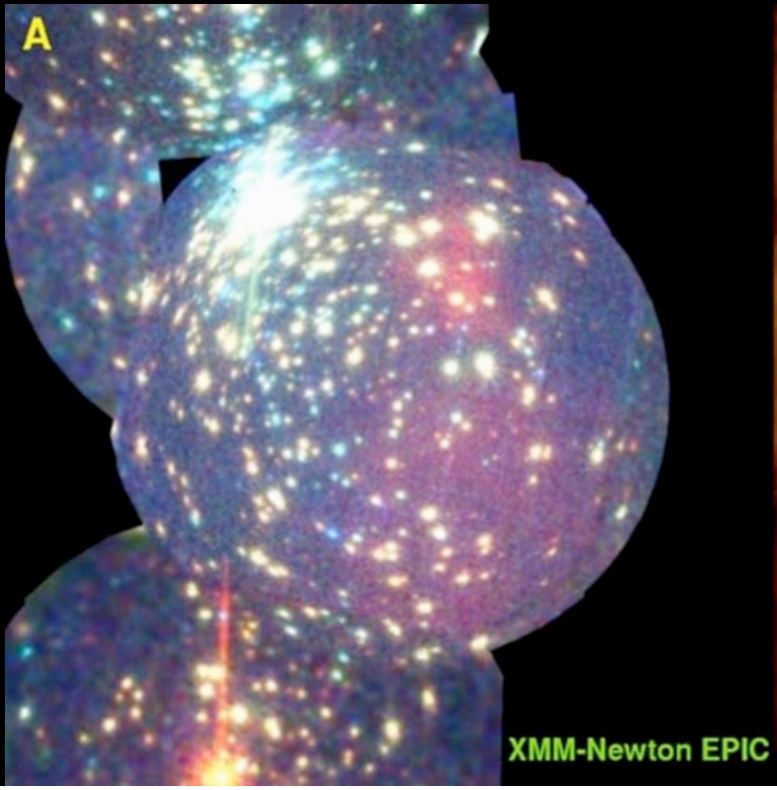
$T \sim 2 \times 10^6$ K

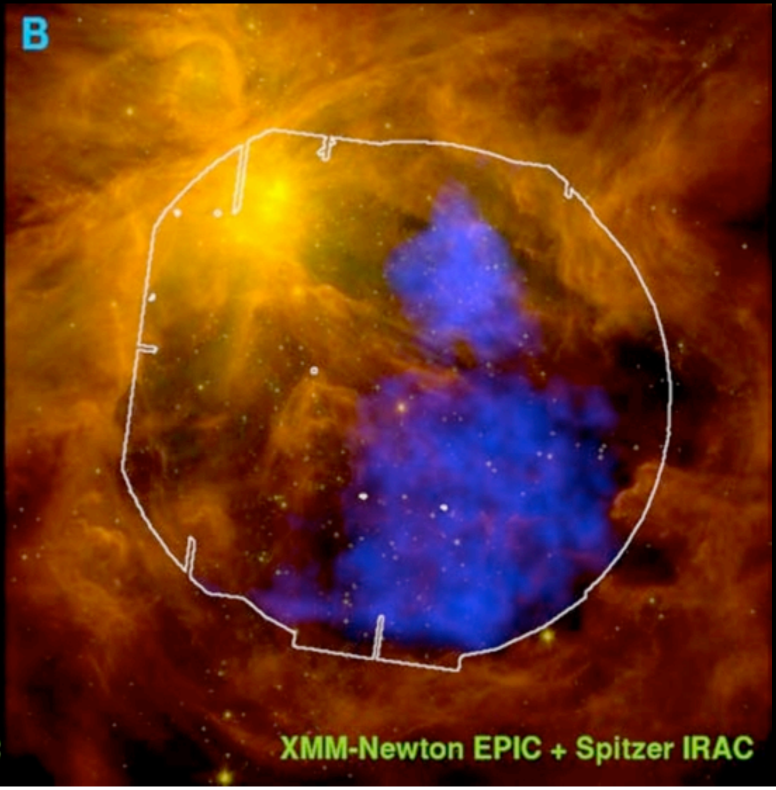
$L_X \sim 5.5 \times 10^{31}$ erg/s

3.5 pc in diameter

Güdel et al. 2008





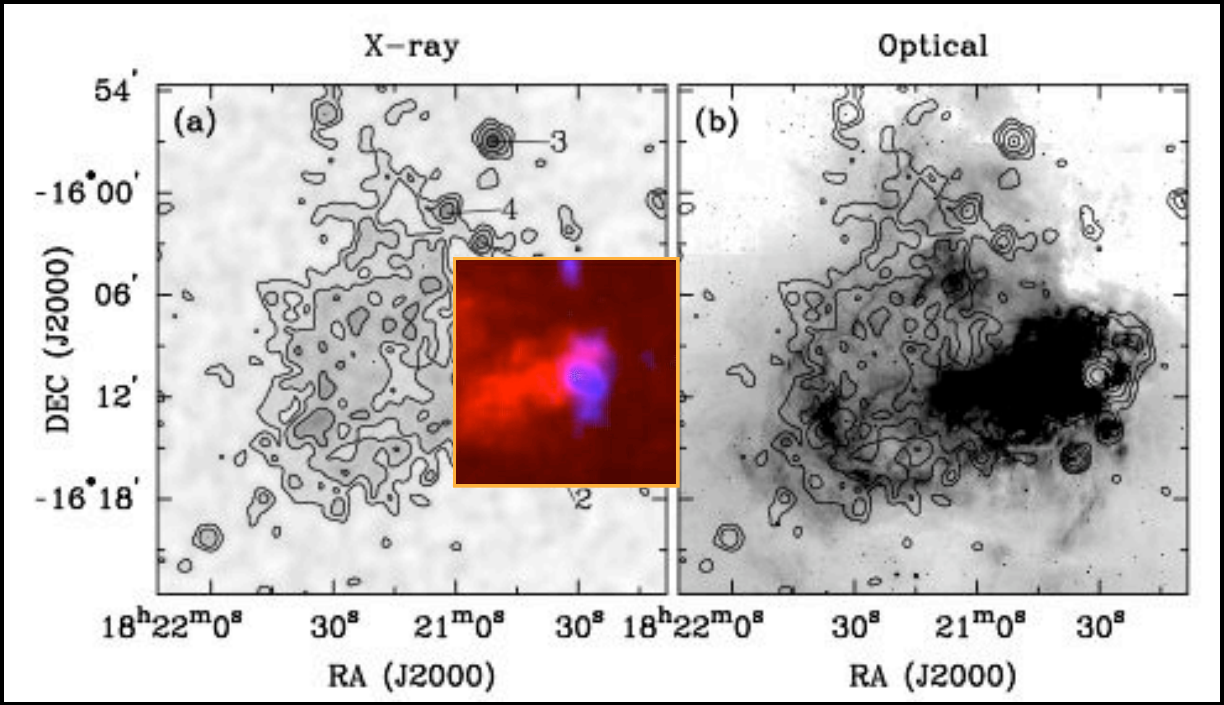


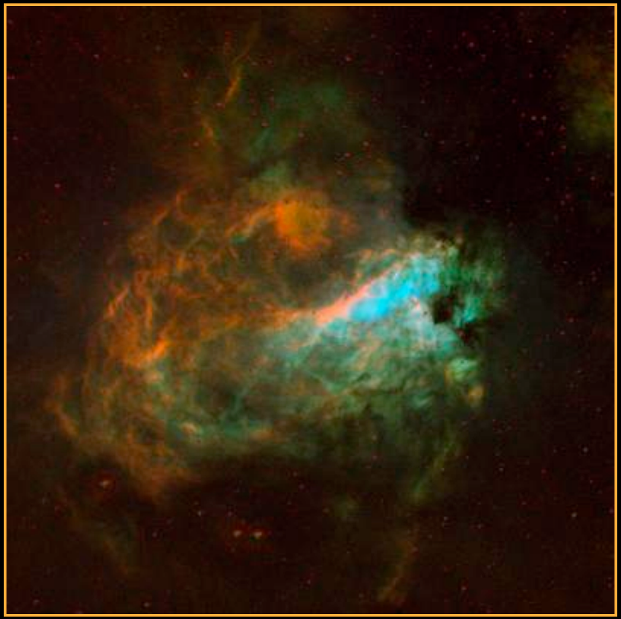
Hot Gas in the Omega Superbubble

Two young superbubbles are detected in X-rays by Chandra: Omega and (Rosette)

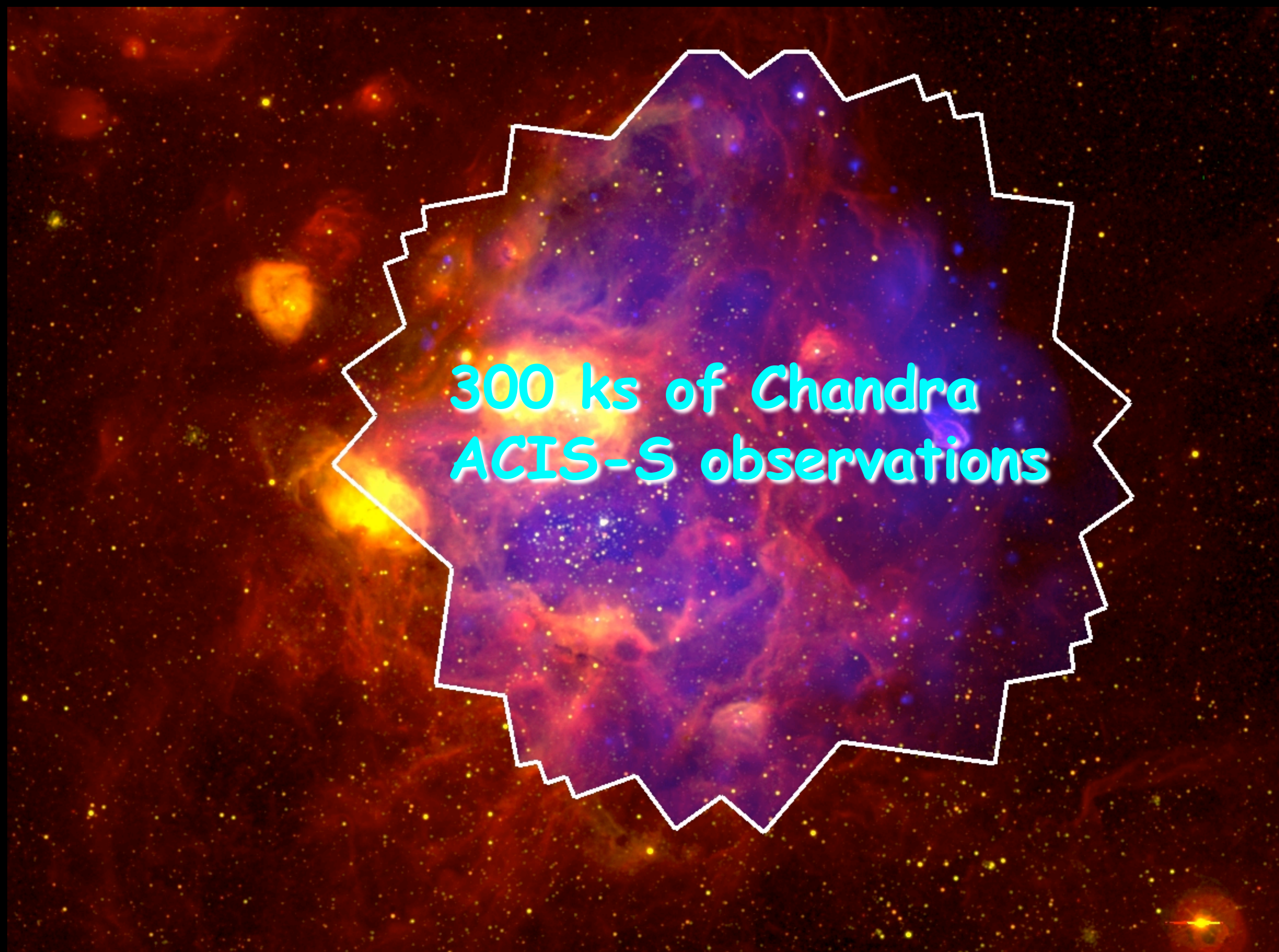
ROSAT - Dunne et al. 2003, ApJ, 590, 306

Chandra - Townsley et al. 2003, ApJ, 593, 874



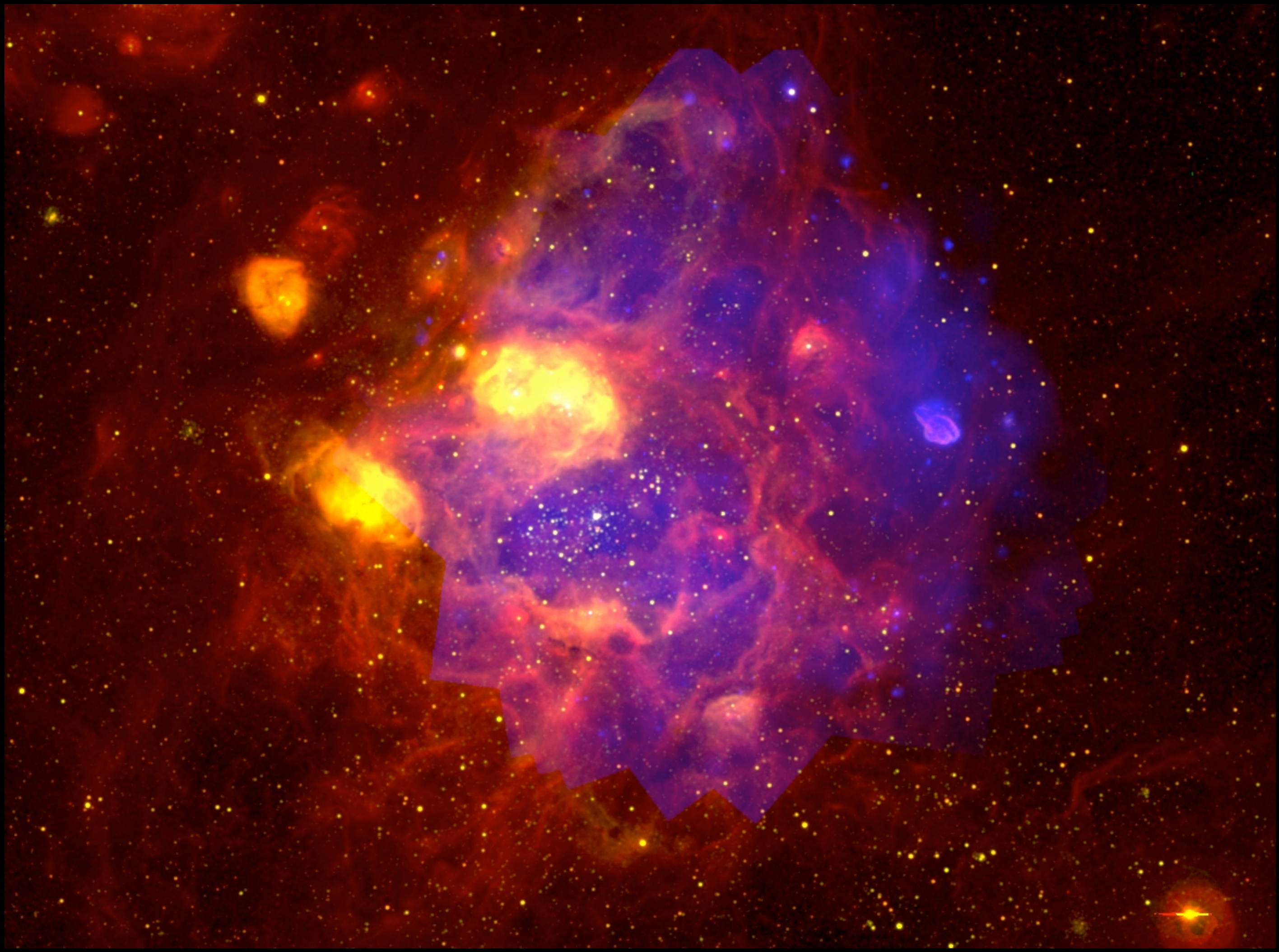


LMC Superbubble: N11



Red: Hα Blue: X-ray

LMC Superbubble: N11



Red: Hα   Blue: X-ray

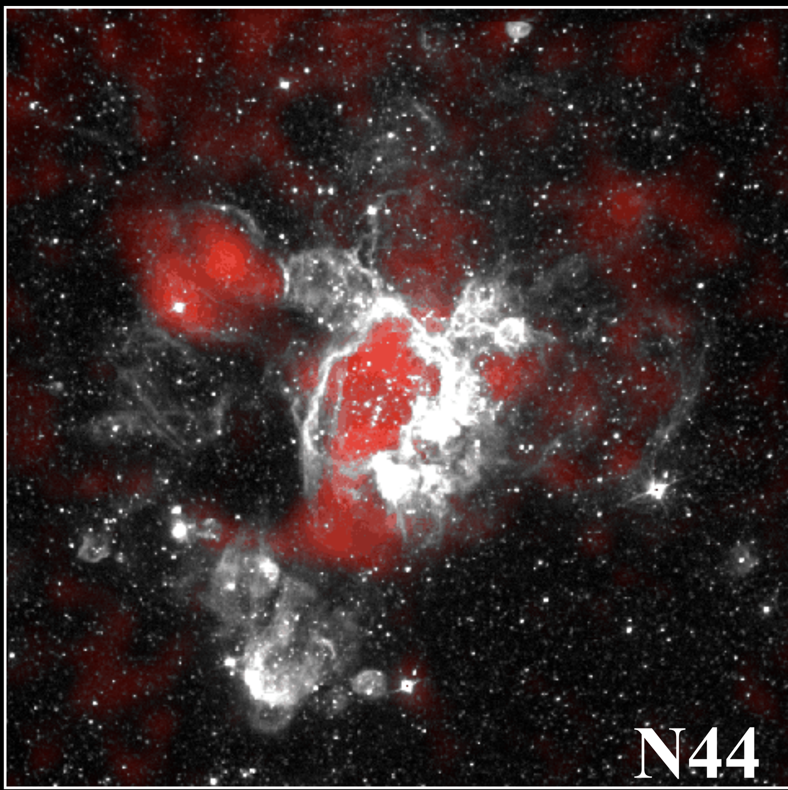
LMC Superbubble: N57

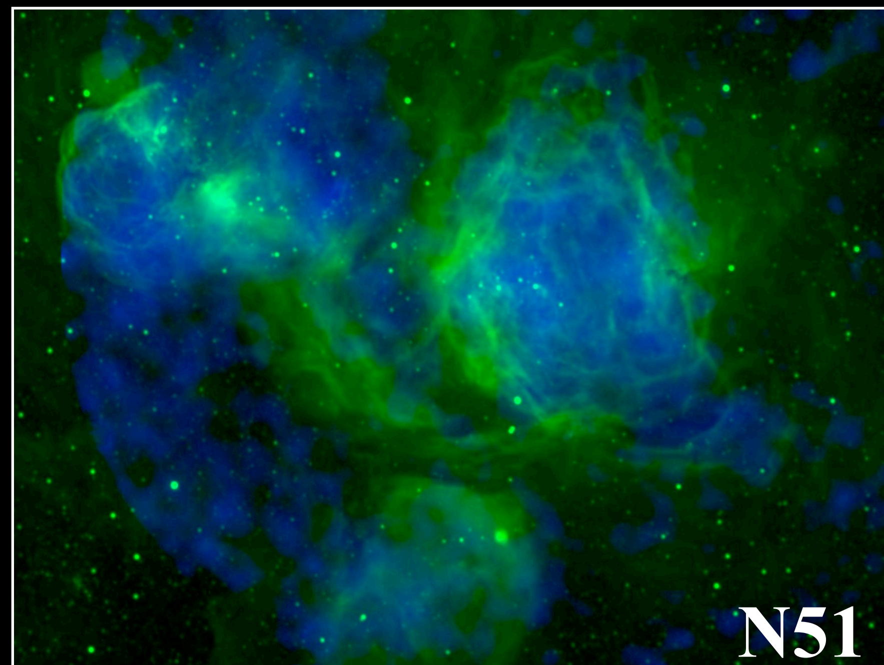
Red: Hα   Green: [O III]   Blue: X-ray

LMC Superbubble: N70

Red: Hα   Green: [O III]   Blue: X-ray

LMC Superbubbles N44 and N51D





Chu et al. 1993, ApJ

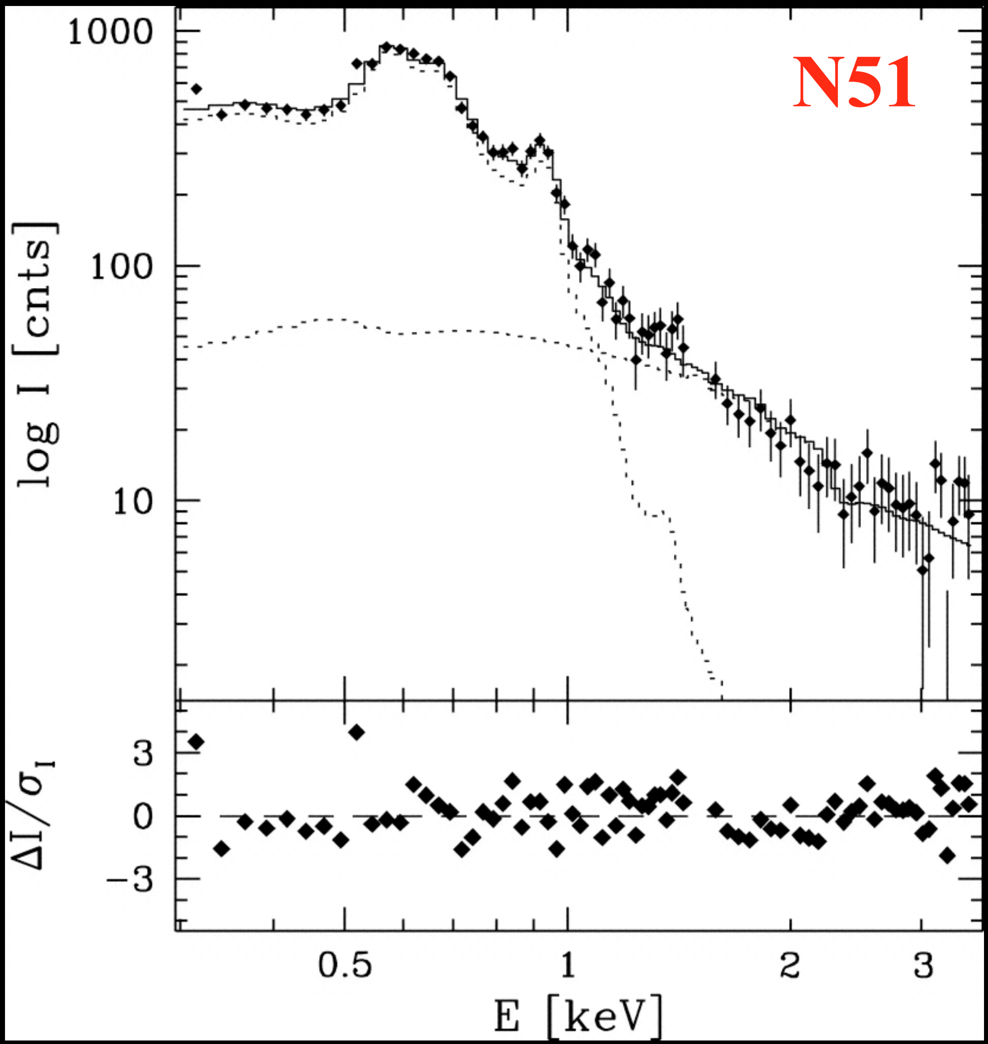
Cooper et al. 2004, ApJ

X-ray Observations of Bubbles

- Detection of hot gas associated with fast winds
  - 12 PNe, 2 WR bubbles, several superbubbles
- Properties of the hot gas:

	T_e [10^6 K]	N_e [cm^{-3}]	L_X [erg/s]
PN	$1\text{-}3 \times 10^6$	100	10^{31} - 10^{32}
WR	$1\text{-}2 \times 10^6$	1	10^{33} - 10^{34}
M17	7×10^6	0.3	10^{33}
Orion	2×10^6	0.2-0.5	5×10^{31}
Eridanus			
LMC SBs	”	”	up to 10^{35}

Nonthermal X-ray Emission



0.2 keV thermal + power-law

30 Dor C - Bamba et al.
- Smith, Wang

RCW38 - Wolk et al.

N51 - Cooper et al.

N11 - Maddox et al.

Parizot et al. 2004

acceleration by repeated shocks and turbulence

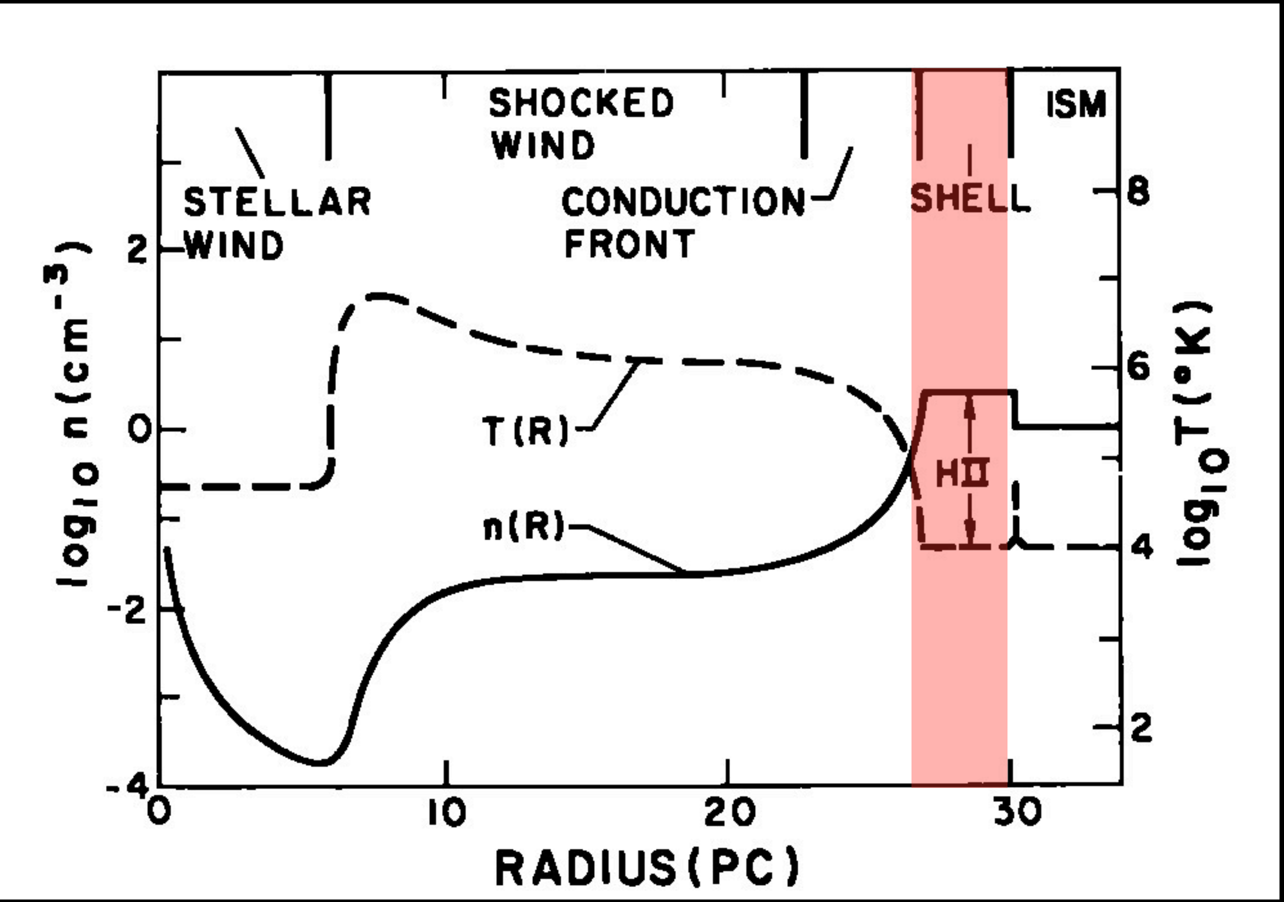
Synchrotron?
Inverse Compton?
???

I. Hot Bubble Interior

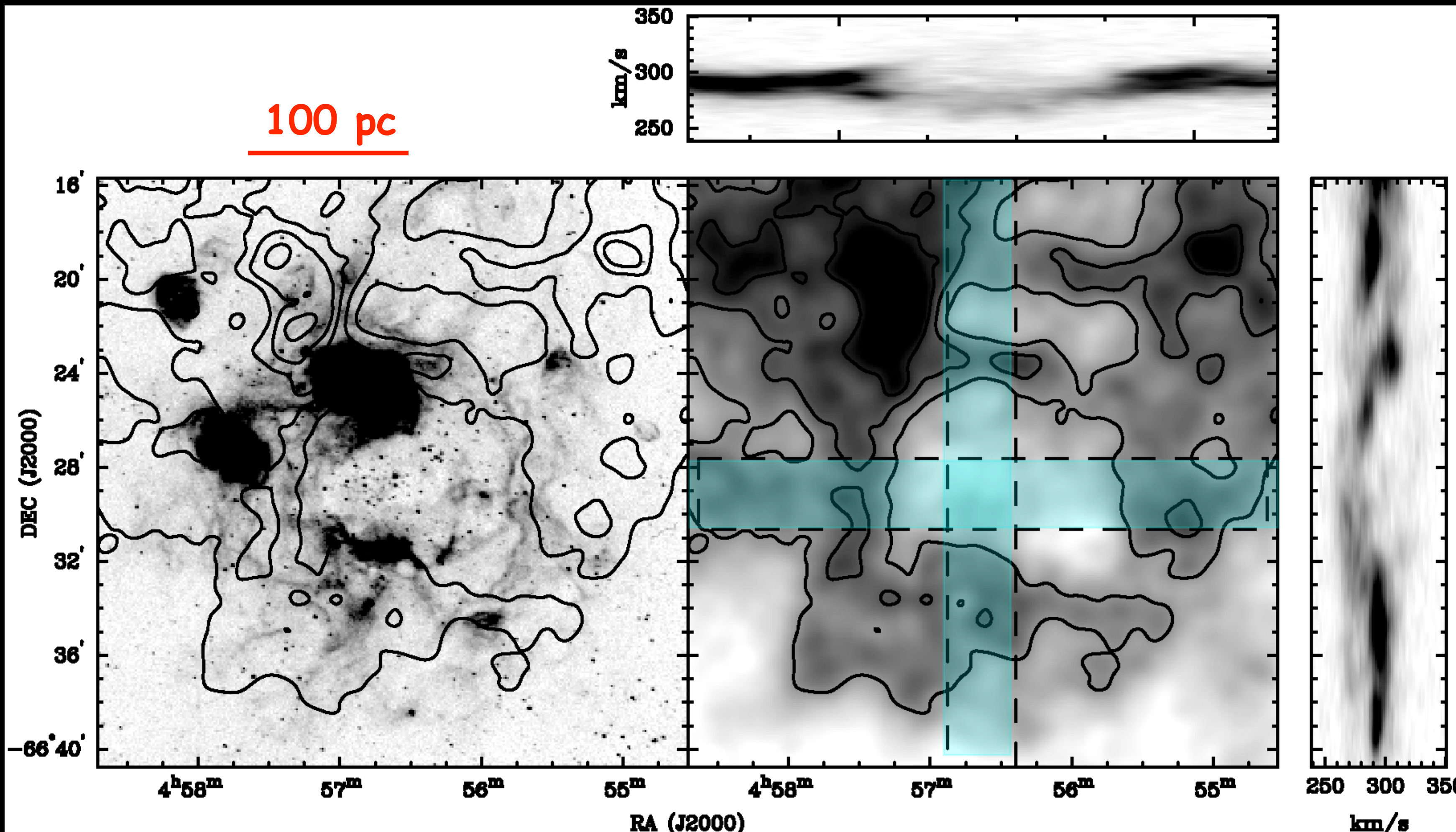
- X-ray emission from bubble interior is soft
- ISM absorbs soft X-ray emission
- X-ray emission depends on:
    - wind properties
    - concentration of massive stars
    - clumpy structure of the ambient medium
    - magnetic fields
    - supernova explosions
- Nonthermal X-ray emission!!!

II. Dense Swept-up Shell

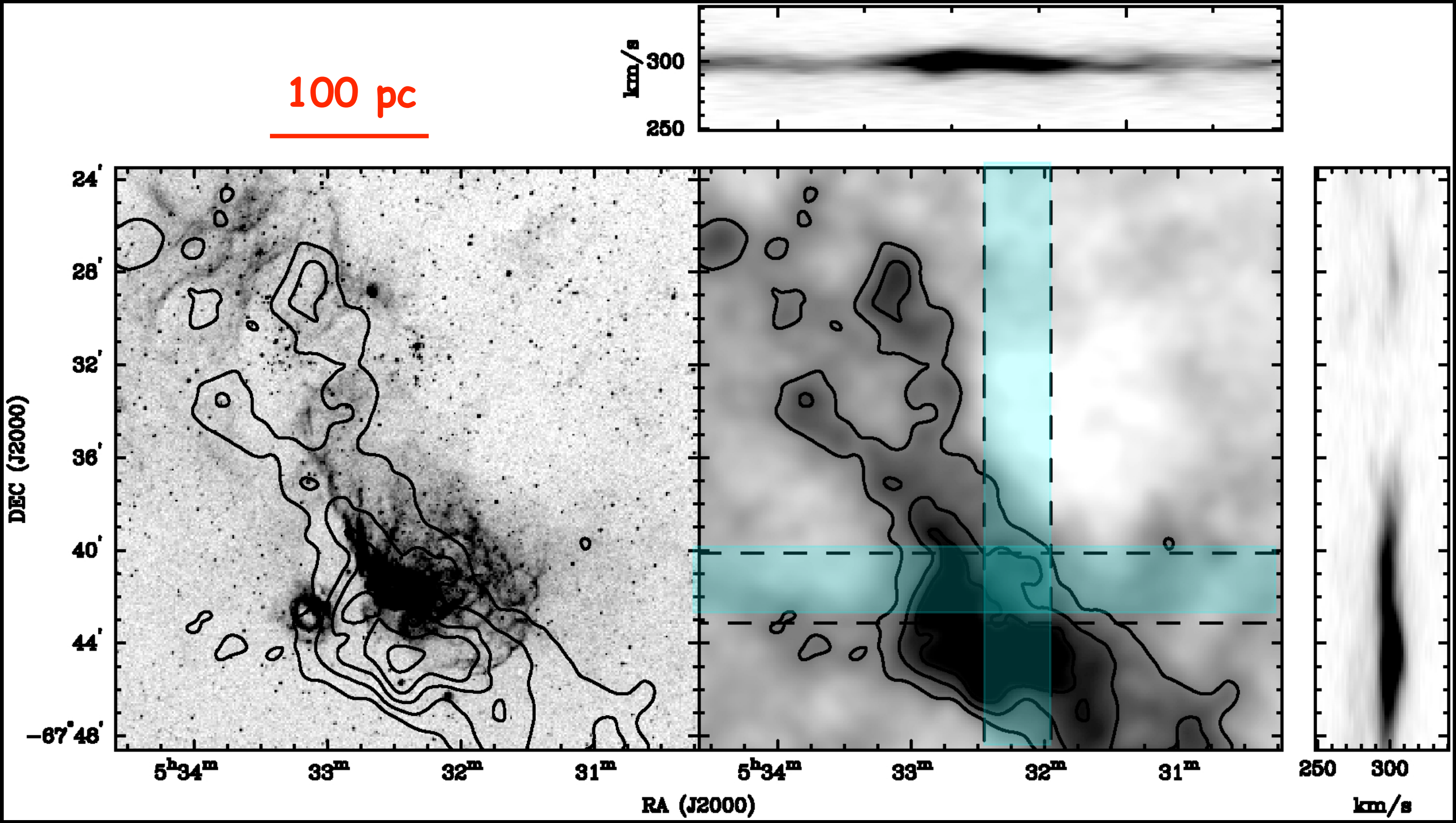
Hα from H II shell, 21-cm from HI shell



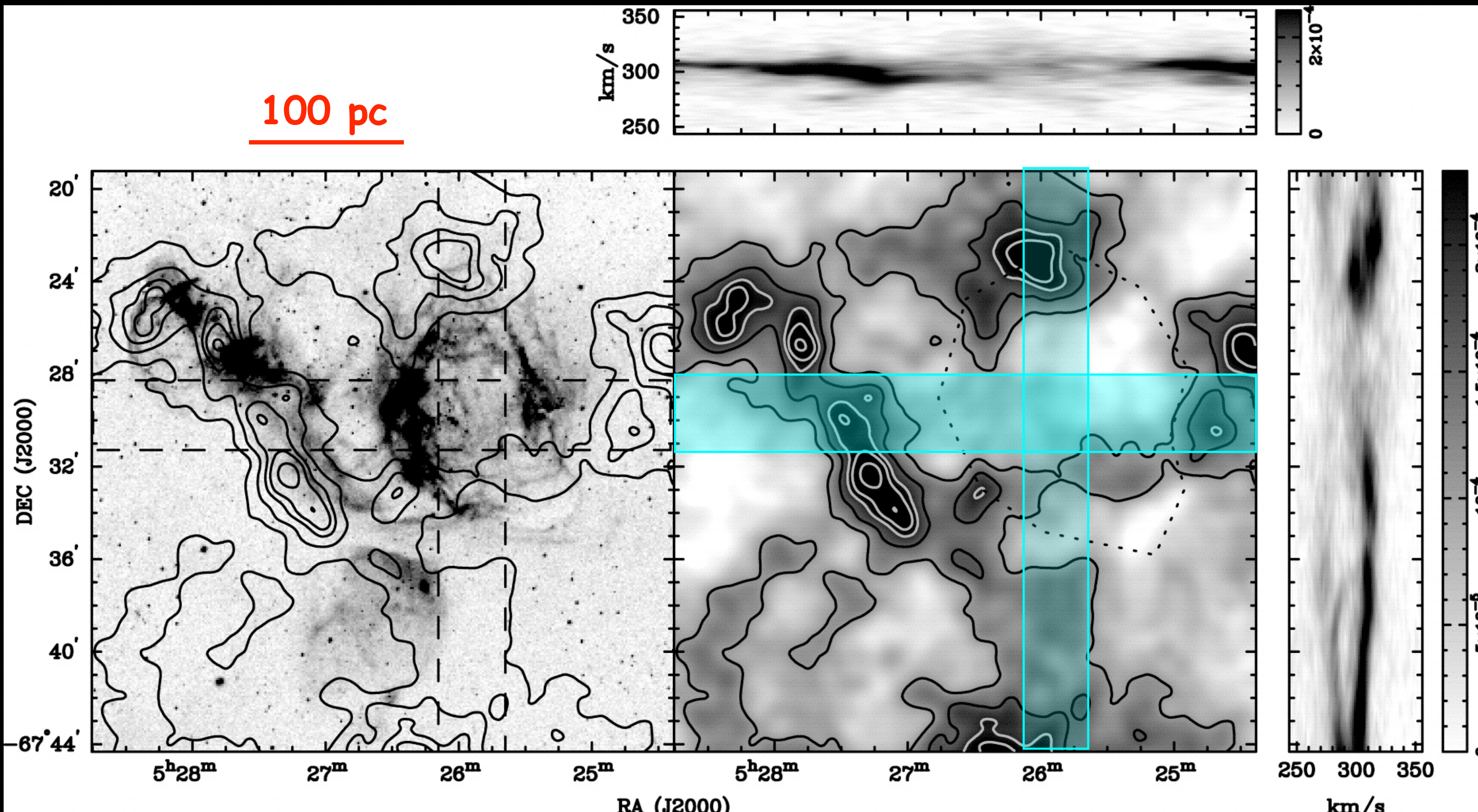
HII and HI Shells of N11



HII and HI Shells of N57

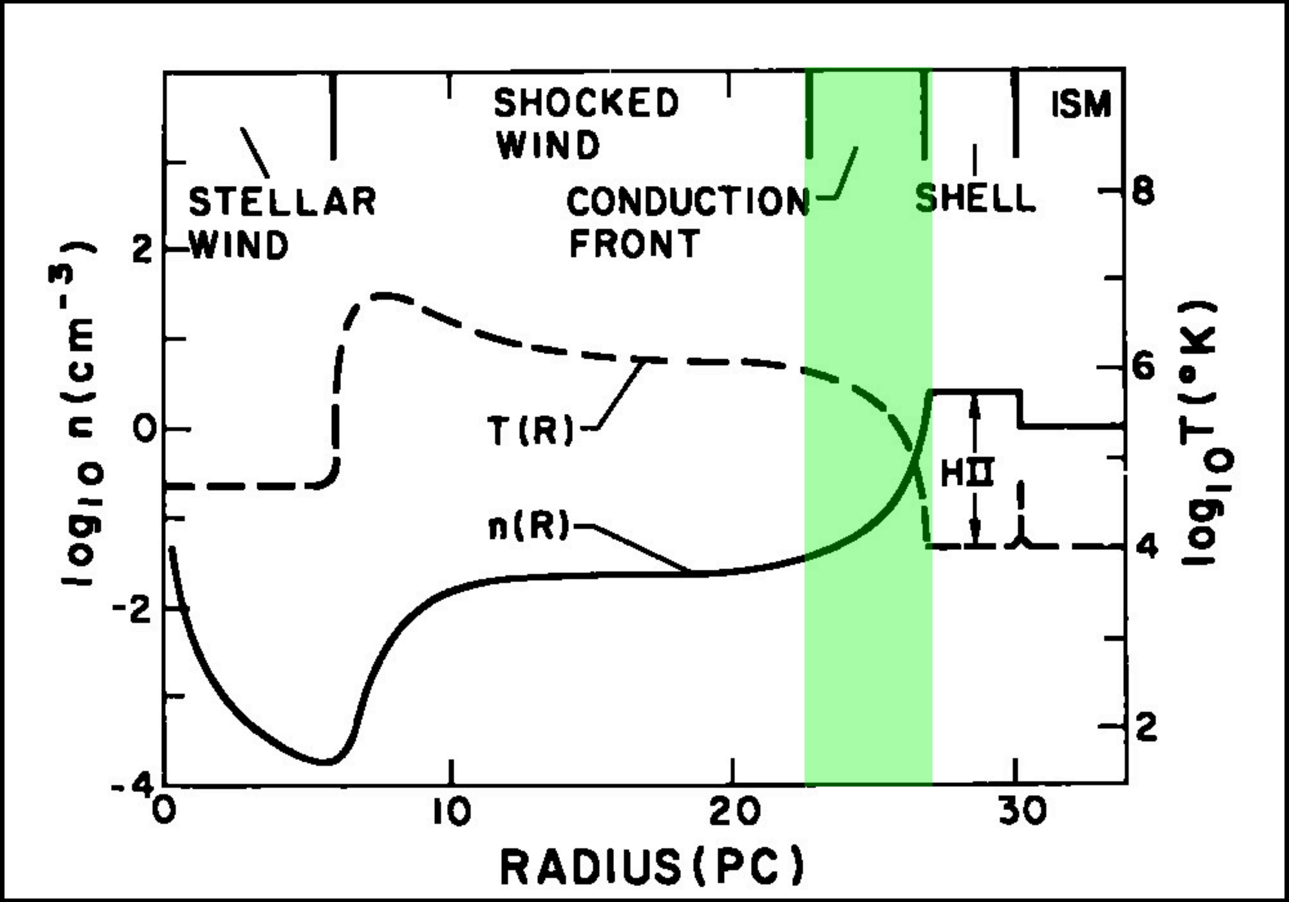


HII and HI Shells of N51



III. Conduction Layer

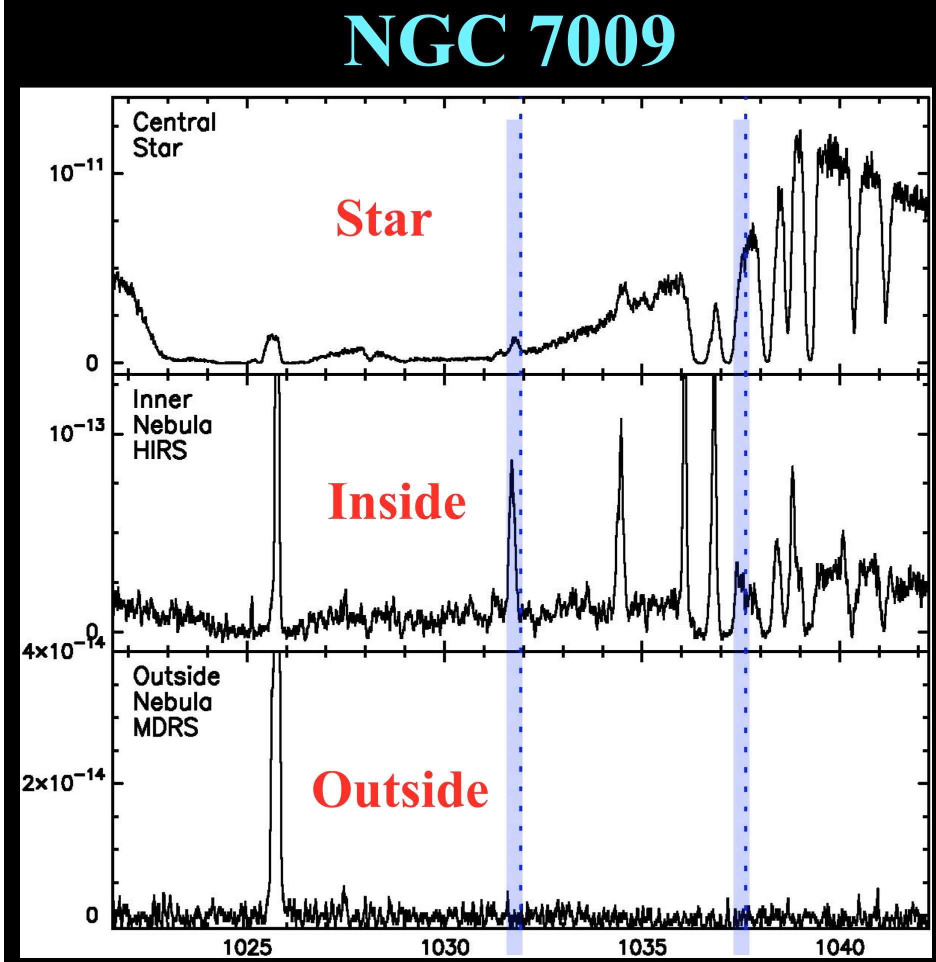
- Probe the thermal conduction layer
  High ions produced by thermal collisions

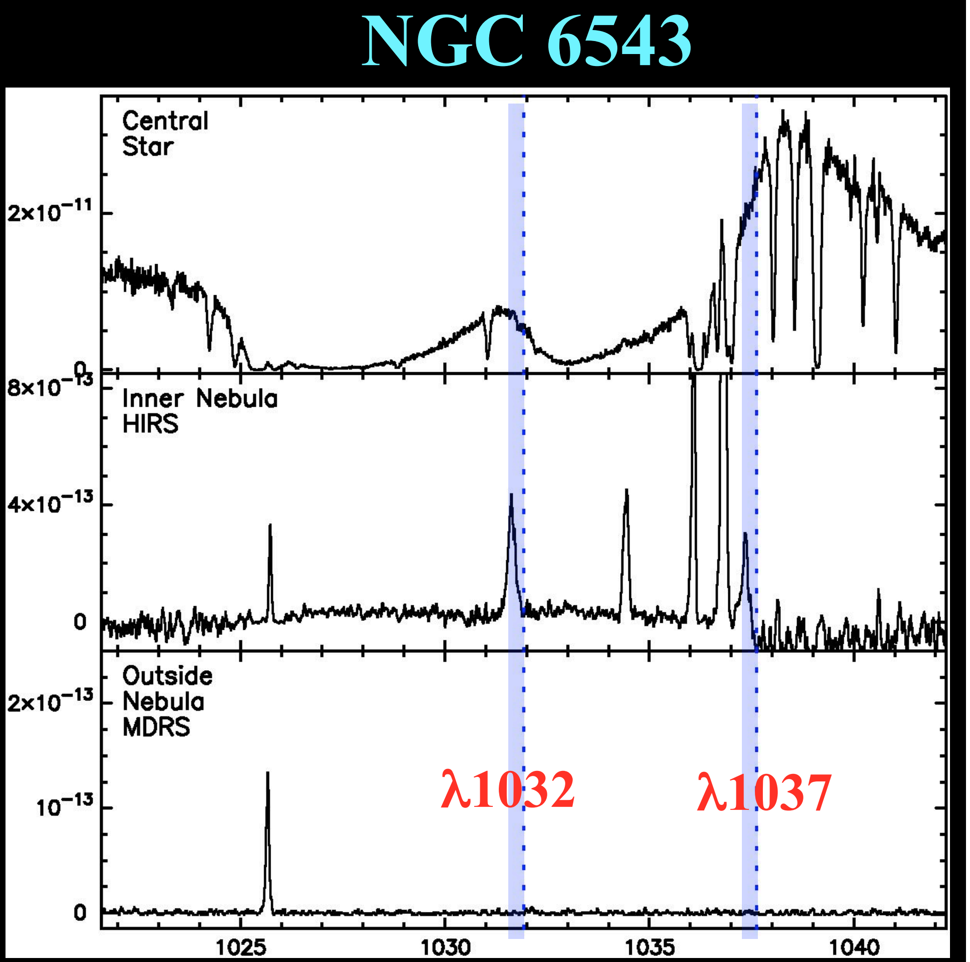


Probes of the Conduction Layer

	C IV	N V	O VI
$\lambda\lambda$ (Å)	1548, 1550	1238, 1242	1031, 1037
Obs.	*HST*/STIS	*HST*/STIS	*FUSE*
I.P. (eV)	47.9	77.5	138.1
T (K)	Collisional ionization		
T^*_{eff} (K)	Photo-ionization		

OVI Absorption vs. Emission

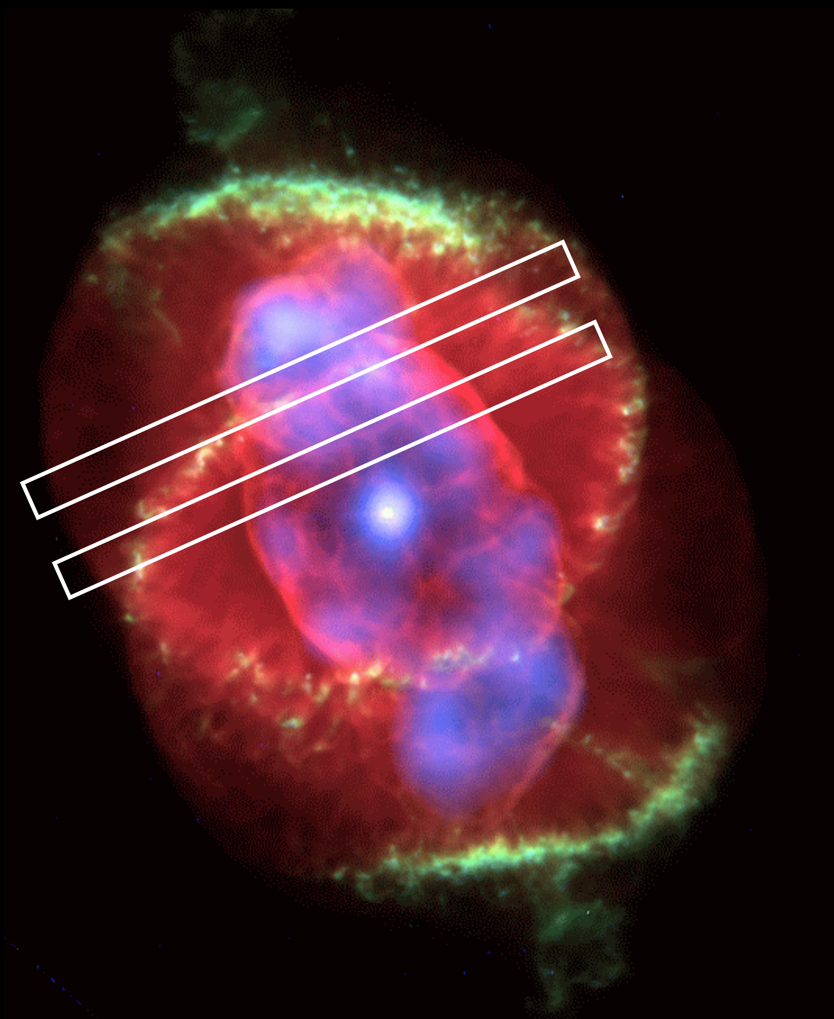




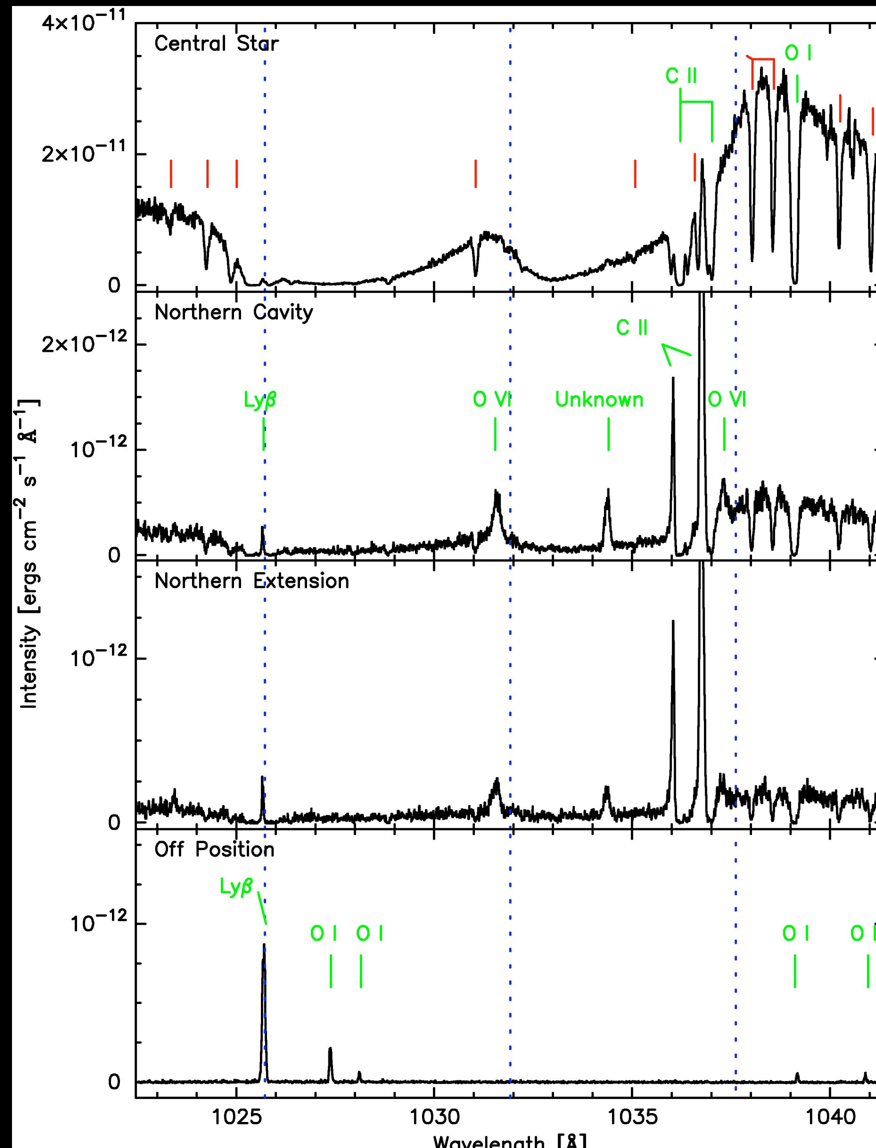
Observations by Iping et al.

Stellar P Cygni profile; nebular O VI emission

FUSE Observations of NGC 6543



Gruendl et al. 2004



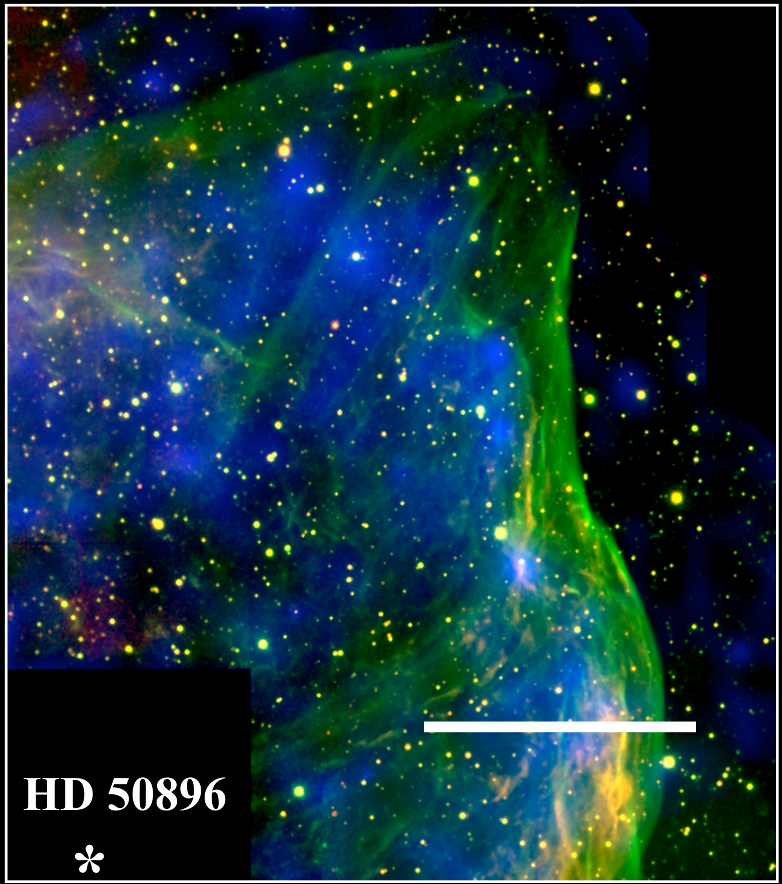
Circumstellar WR Bubble S 308

Boroson et al. (1997) detected N V absorption from the conduction layer.

HST STIS observation of N V and C VI emission was scheduled, but STIS died.

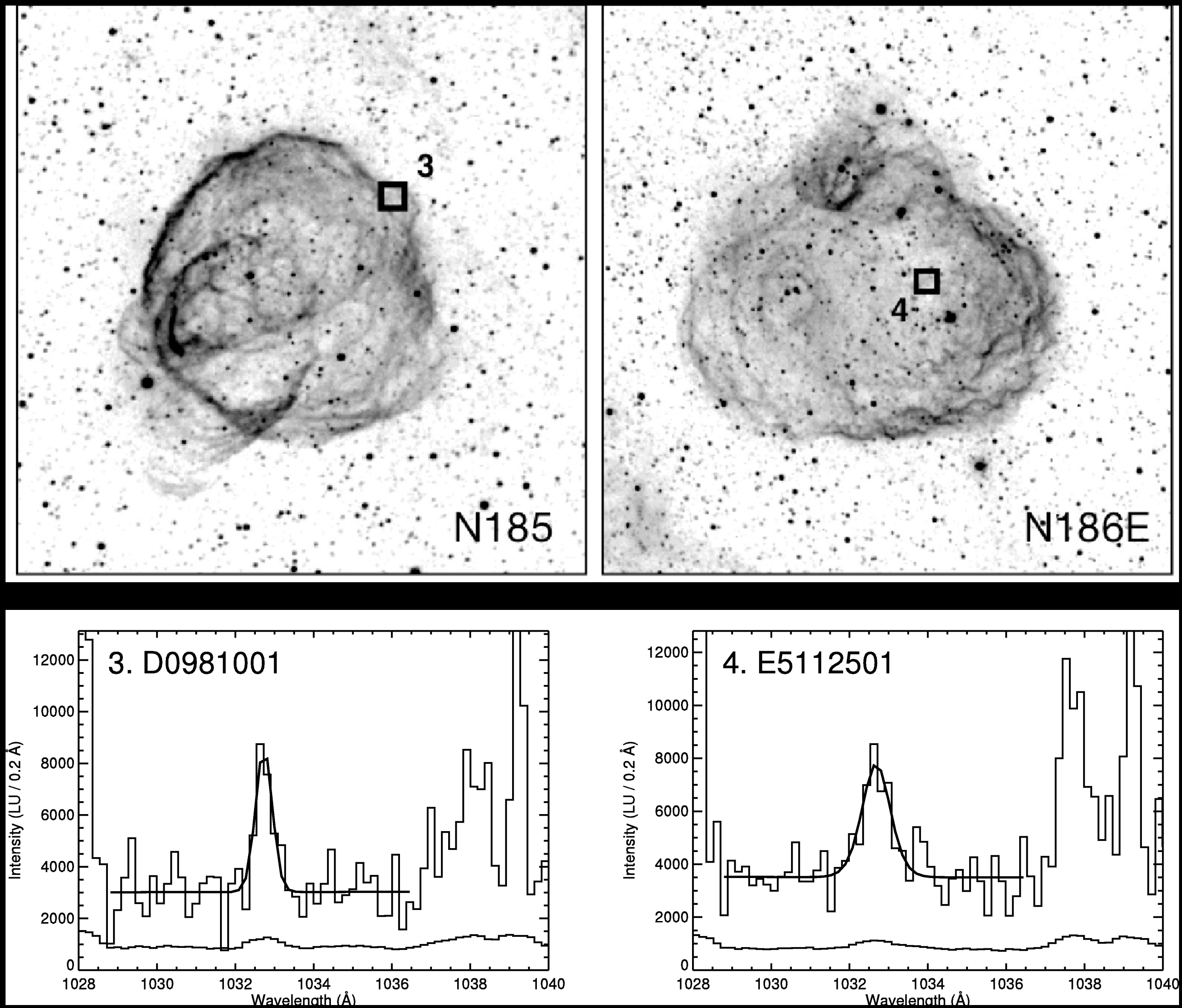
FUSE observations of O VI were awarded, and it died, too.

Spitzer can observe Ne V, but it is running out cryogen.



R: Hα G: [O III] B: X-ray

O VI Emission Detected in Superbubbles N185, N186E
Sankrit & Dixon 2007



III. Conduction Layer

- Probe the thermal conduction layer with high ions produced by thermal collisions

- NGC 6543: given the boundary conditions of hot interior and warm shell, thermal conduction appears to be consistent, but does not explain the low X-ray luminosity.

- O VI emission studies avoid contamination from hot halo gas
  SPEAR - O VI emission from Eridanus
  (Kregenow et al. 2006)

Final Words

Multi-wavelength observations are needed to study the physical structure of ISM bubbles.

ISM bubbles need to be studied in conjunction with the history and distribution of massive Star formation.